Jet Shapes in CMS

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(on behalf of CMS collaboration)

Special thanks to the authors of:
Jet Transverse Structure and Momentum Distribution in pp Collisions at 7 TeV
(CMS PAS **QCD-10-014**)
**Jet charged component structure at 7 TeV**
(CMS PAS QCD-08-002)
and
Classical jet shape analysis (CMS PAS QCD-08-005)

Boston Jet Physics Workshop   January 14 , 2011

Outline of the talk

❑   Introducing Jet Shapes - definitions of observables

❑   Measurements in previous collider experiments.

❑   Observable quantities:

    ❑ Fraction of jet transverse momentum (Classical definition)

    ❑ Charged component structure

❑   Integrated jet shapes

❑   Sensitivities to PYTHIA tunes and Jet Fragmentation

❑   Charged multiplicity

❑   Quark / gluon shape differences

❑   Summary

Hadronic interactions
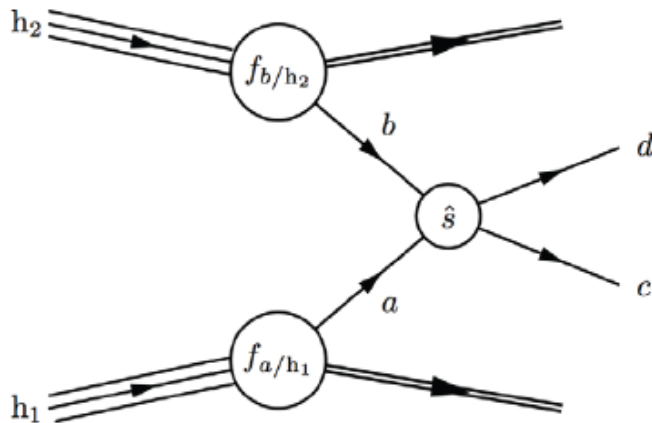
Hadron Colliders:
- Higher energies
- Only small fraction of initial particles participate in hard interaction
- Rest goes into underlying event
- Total CM energy of each interaction not known.

Collisions involving outgoing quarks and/or gluons:
- QCD theory
- Fragmentation + hadronization processes
  - Initial parton -> set of hadrons
- Jets
  - Hadrons (or tracks or energy deposits in calorimeters)
    - Mostly close to direction of initial parton
  - Many different algorithms to define the jet objects
    - Want jet energy as close as possible to initial partons
  - Jet defined by direction and energy
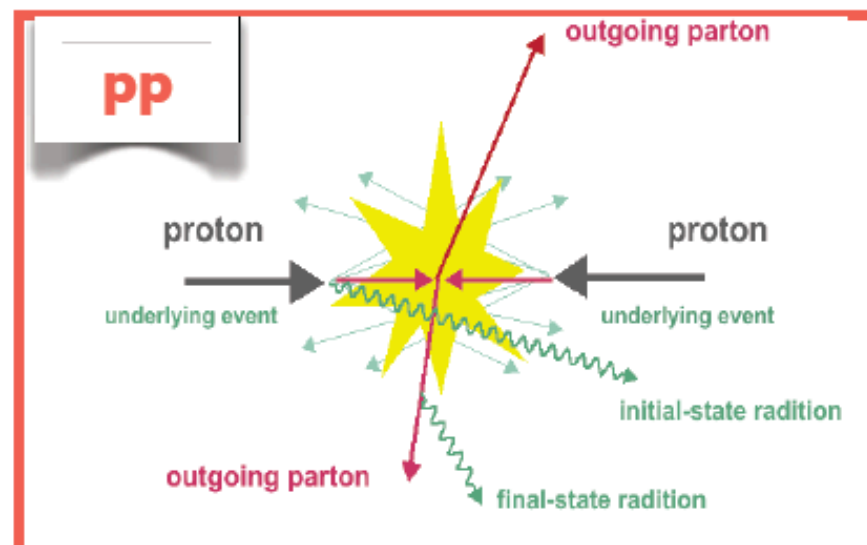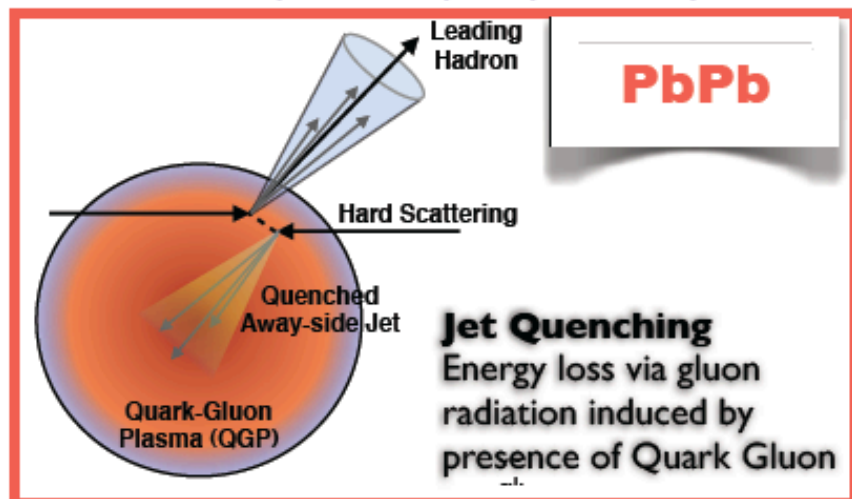   - Cone algorithms also by cone size.
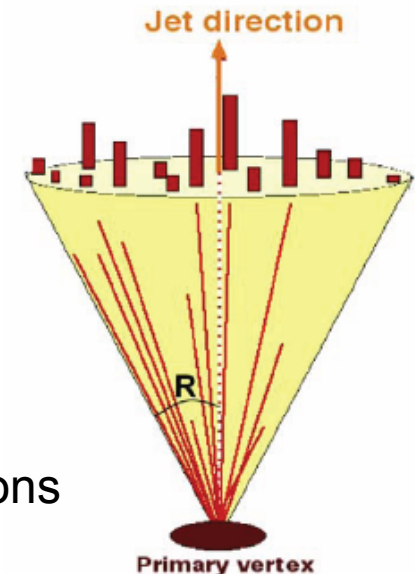
Motivation (Jet shapes)

Jet shapes measure the average distribution of energy flow as a function of the distance away from the jet axis.
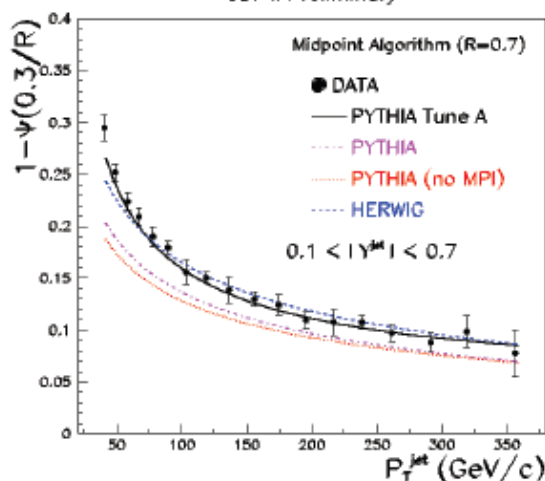
- ❑ Test showering models in Monte Carlo generators.
- ❑ Discriminates between different underlying event models.
- ❑ Sensitive to the quark / gluon jet mixture.
- ❑ Provide insight into performance of jet clustering algorithms.
- ❑ Jet shapes can discriminate between competing models of jet quenching which have all successfully described leading particle suppression in Relativistic Heavy Ion Collider (RHIC) data.

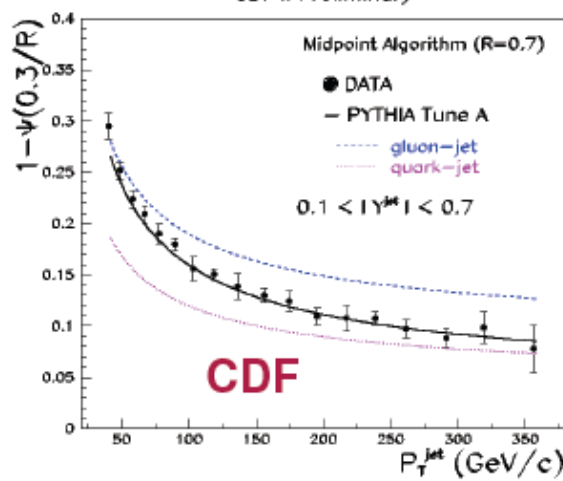
arXiv:0810.2807 (Ivan Vitev (LANL) and et. al)

Leading Hadron

PbPb

Hard Scattering

Quenched Away-side Jet

Jet Quenching
Energy loss via gluon radiation induced by presence of Quark Gluon

Quark-Gluon Plasma (QGP)

PP

outgoing parton

proton

proton

underlying event

underlying event

initial-state radition

outgoing parton

final-state radition

Tevatron and HERA results

CDF II Preliminary

Midpoint Algorithm (R=0.7)
- DATA
- PYTHIA Tune A
- PYTHIA
- PYTHIA (no MPI)
- HERWIG

$0.1 < |Y^{jet}| < 0.7$

CDF II Preliminary

Midpoint Algorithm (R=0.7)
- DATA
- PYTHIA Tune A
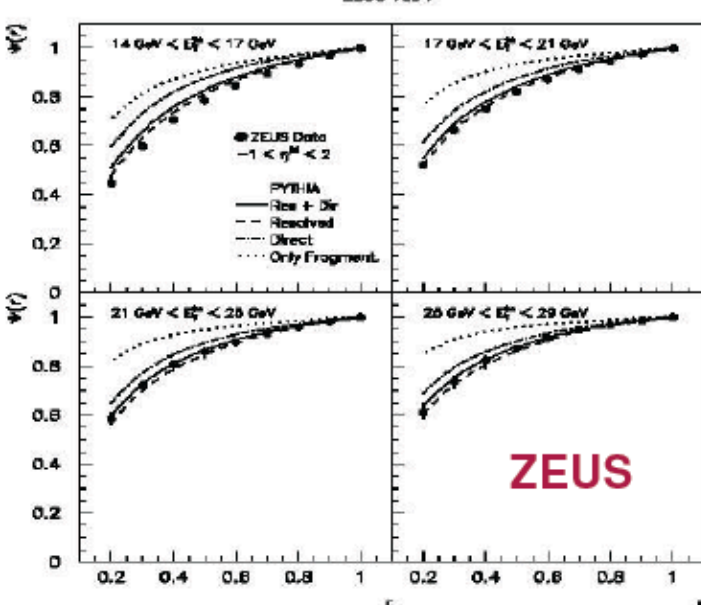- gluon-jet
- quark-jet
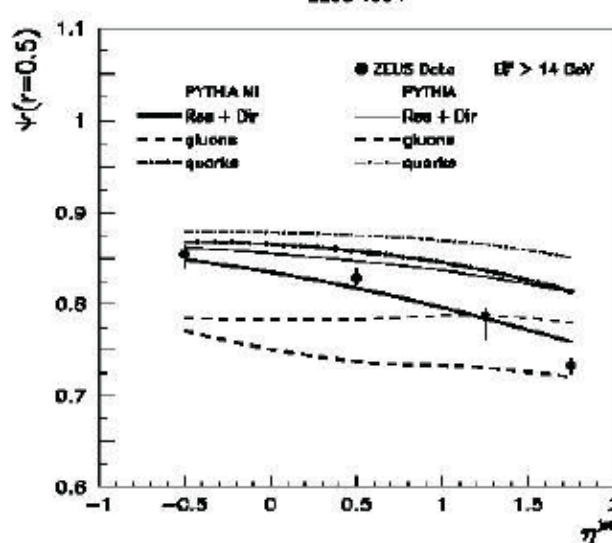
$0.1 < |Y^{jet}| < 0.7$

CDF

Recaps from CDF:
- PYTHIA TuneA describes data well
- Herwig also reasonably good
- Tune of the MC to underlying event is important
- Multiple interactions are consequential
- Shapes get narrower as p_T increases.

⇒ fraction of quark gluon jets changes
⇒ Running of strong coupling.

ZEUS 1994

ZEUS

ZEUS 1994

Recap for ZEUS :
- Jet shape broadens as η increases, and narrows as MET increases.
- The removal of ISR and FSR in MC gives rise to jet shape which are too narrow compared to data.
- The observed broadening of the jet shape as increases is consistent with an increase of the fraction of gluon jets independent of the effects of a possible underlying event.

Event selections for Jet Shape

❑   Condition on the Technical Trigger bits:
Coincidence for jets with low transverse momentum (p_T < 40 GeV) a minimum bias trigger was used which requires activity in both beam scintillator counters located at 3.23 < $|\eta|$ < 4.65 in coincidence with colliding proton bunches.

❑ Jets are reconstructed from
  ❑ using calorimeter tower information (calojets) or
  ❑ using a combination of information from the calorimeters and the tracker (jet+track algorithm).

❑ Jets were selected requiring at least one of the leading jets within |eta|<1.

❑ The two leading jets pass satisfy the jet Id criteria to get rid of the noise.

❑ Anti-kT cone algorithm applied with cone size=0.7

❑ After jet energy correction is applied the corrected jets satisfy: p_T>15 GeV.

Calorimeter Jet Shapes in η-φ plane
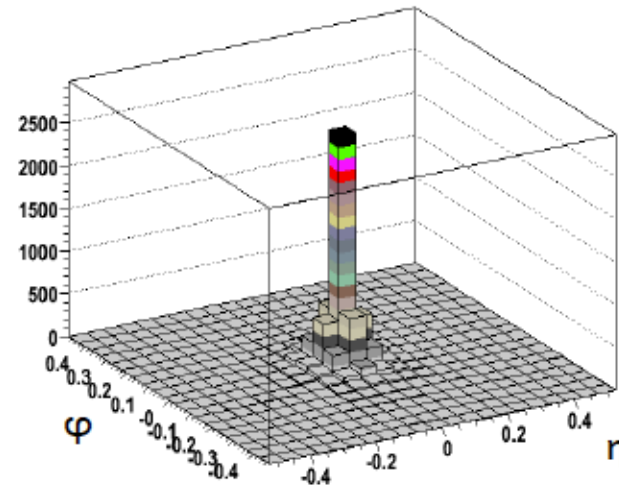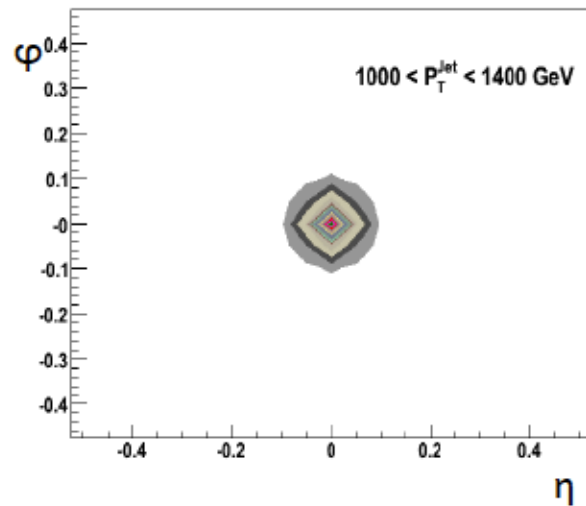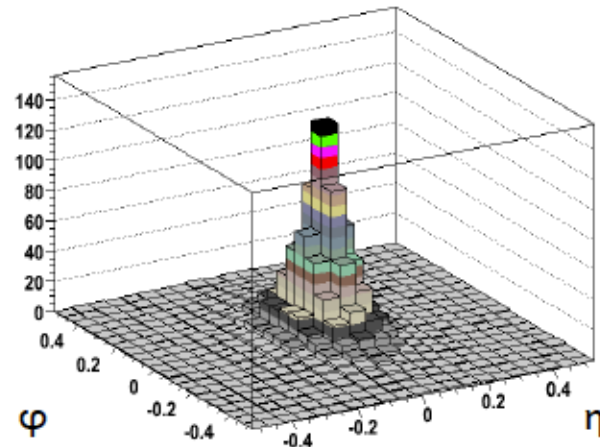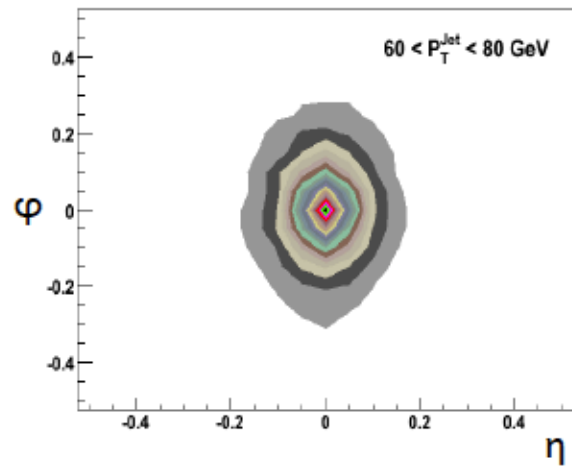
Jet shape in j direction is wider due to bending of charged particles in B field.

Jet charged component

The following observables are used to characterize the structure of jets.

- Charged particle multiplicity in jet (N_{ch}).

- Charged particle transverse shape variable (δR^2)
  A measure of the width of a jet in the η-Φ plane.

$$< \delta R^2 > (p_T) = < \delta \varphi^2 > (p_T) + < \delta \eta^2 > (p_T)$$

$$< \delta \eta_{jet}^2 > (p_T) = \frac{\sum_{i \in jet} (\eta_i - < \eta >)^2 \cdot p_T^i}{\sum_{i \in jet} p_T^i}$$

$$< \delta \phi_{jet}^2 > (p_T) = \frac{\sum_{i \in jet} (\phi_i - < \phi >)^2 \cdot p_T^i}{\sum_{i \in jet} p_T^i}$$

N_{ch} and δR^2 for jet flavors (Dijets)

o The combination with minimum:

$$\sum \Delta R^2(parton, jet) = \Delta R^2(i_1, j_1) + \Delta R^2(i_2, j_2)$$

**PYTHIA, |η|<1
Detector level**
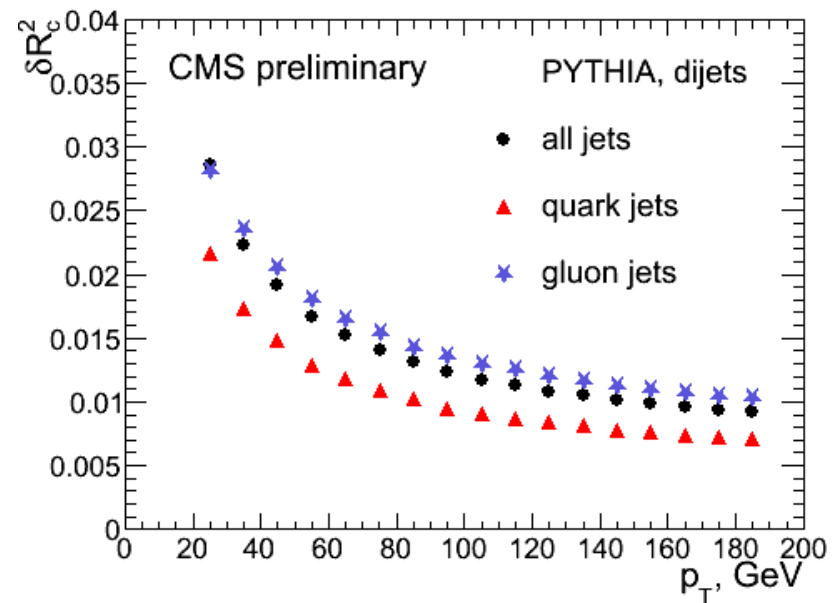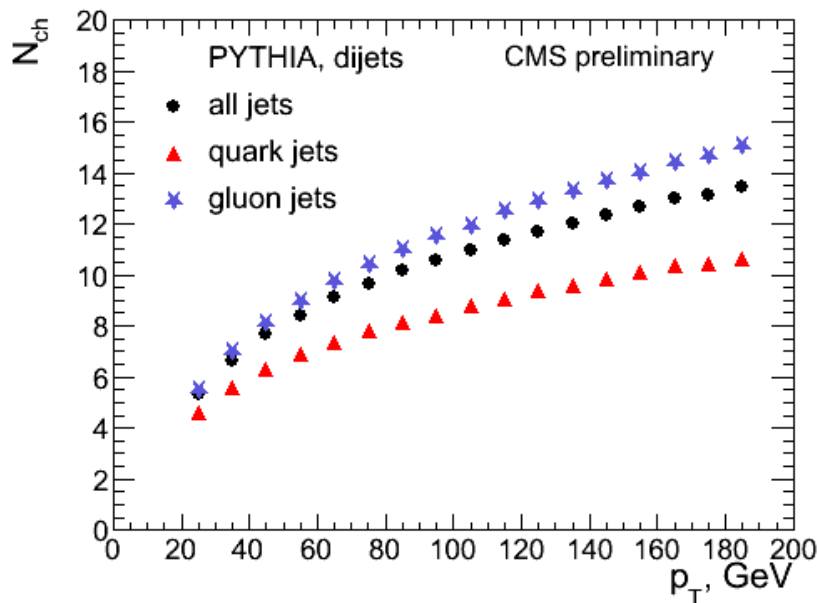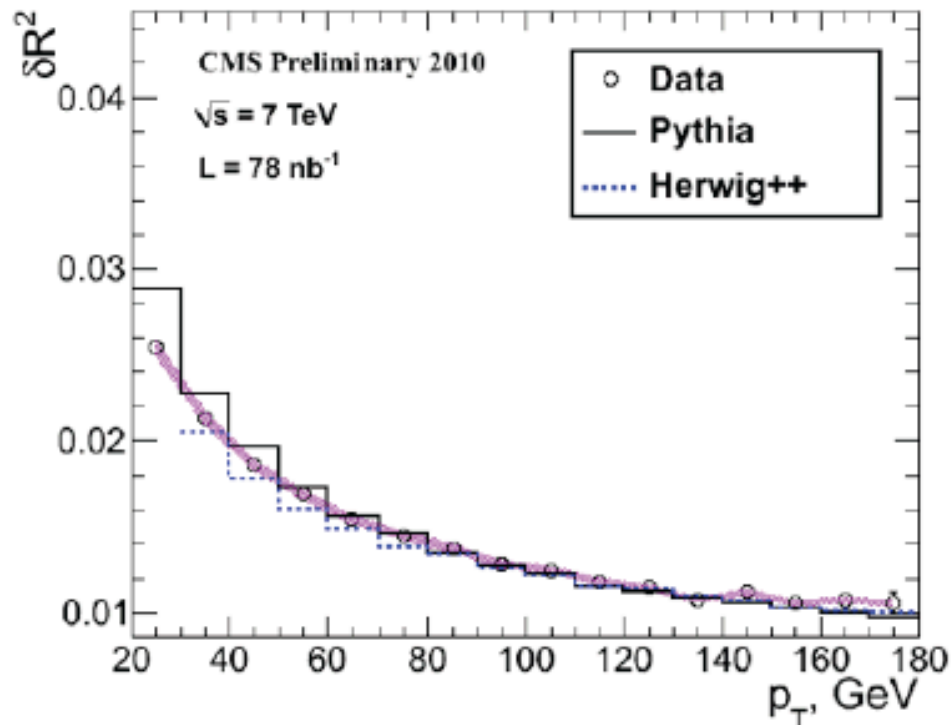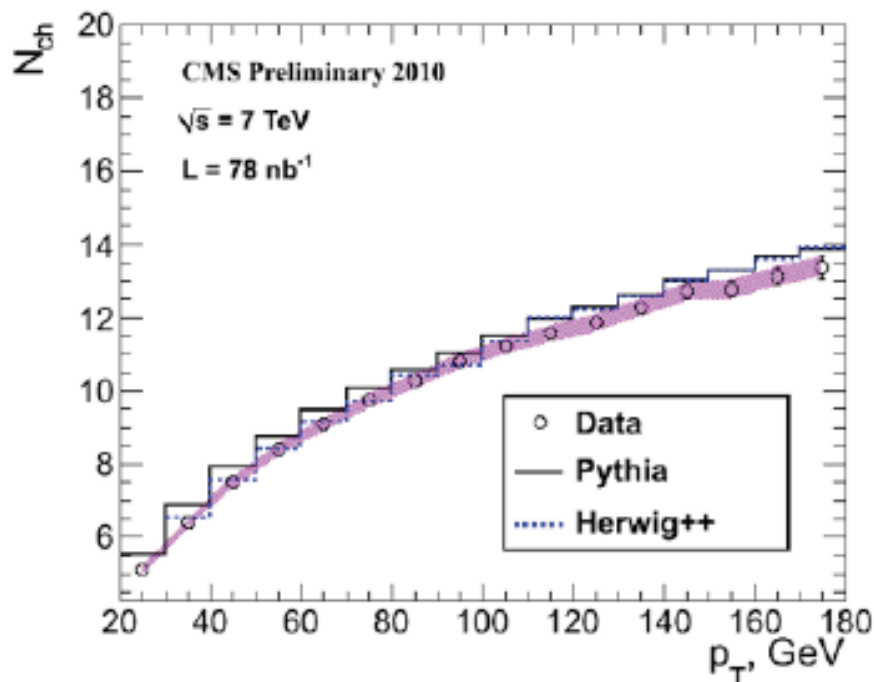

■ The mean charged particle multiplicity increases whereas the transverse jet shape δR^2 drops as a function of the jet transverse momentum.

# Charged multiplicity (N_{ch}) and δR^2 vs p_T^{jet}

Data, PYTHIA, HERWIG jets with $|\eta| < 1$ (detector level)

Dijets

- Statistical uncertainty is assigned to data points.
- Systematic uncertainty due to jet energy scale is shown with a pink band.

❑ At low jet transverse momentum (20< pT <50GeV) the measured jets are a few percent broader than predicted by Herwig++ and narrower than predicted by Pythia D6T.

Classical Jet Shapes Measurements

$$R = \sqrt{\Delta y^2 + \Delta \varphi^2}$$
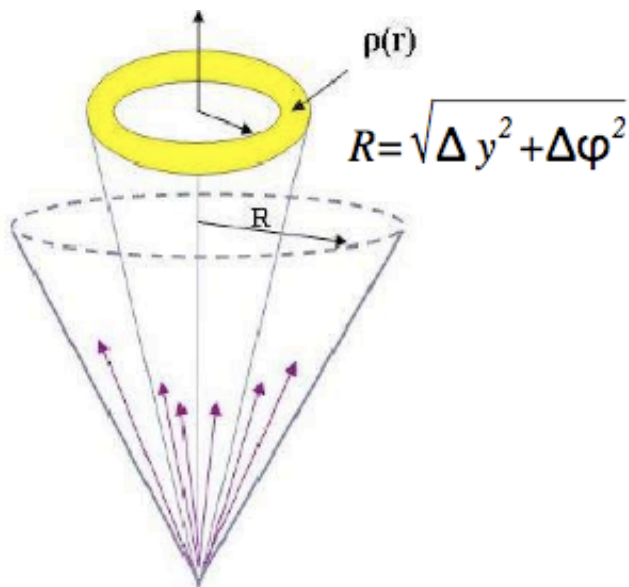
Differential Jet Shape

Definition : Integrated jet shape is defined as the average fraction of jet transverse momentum inside a <u>cone</u> of radius r concentric to the jet axis.

$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0;r)}{P_T^{jet}(0,R)}$$

Definition: The average fraction of the jet transverse momentum inside an <u>annulus</u> in the y-Φ plane of inner (outer) radius r-Δr/2 (r+Δr/2) concentric to the jet axis.

$$\rho(r) = \frac{1}{\delta r} \frac{1}{N_{jet}} \sum_{jets} \frac{P_T(r - \delta r/2, r + \delta r/2)}{P_T(0,R)}$$
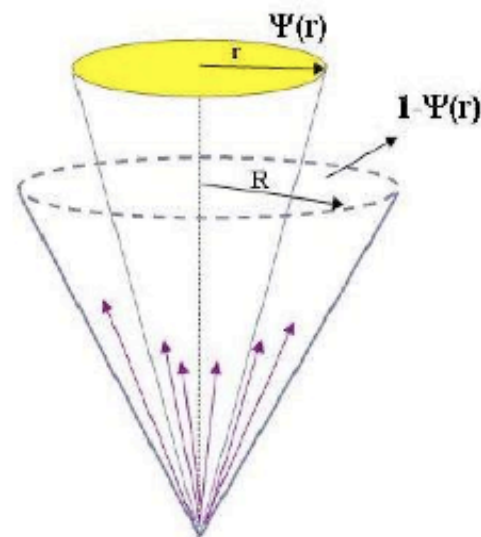
Integrated Jet Shape

Systematic uncertainty

❑ Jet energy scale.

❑ Calorimeter Response and Transverse Shower Shape
  ➢ The measured jet shapes depend on the calorimeter response to hadrons and on the transverse showering. There is uncertainty due to simulation of these effects.
    o Data driven approach to estimate the sensitivity of the jet shapes to the calorimeter resolution by looking track jet shapes and calorimeter level jet shapes.
    o Hadrons deposit energy in several neighboring towers. This transverse showering affects the measured jet shapes.

❑ Jet fragmentation
  ➢ The calorimeter response simulation, and hence jet shape corrections, depends on the fragmentation model.
  ➢ To determine systematic uncertainty due to the fragmentation model we compared the jet shape correction factors for Pythia D6T and Herwig++.

Jet energy scale

Current expectation of the JES uncertainty at start up is ±10% **(JME-07-002)**.
Changing JES affects jet shapes as jets migrate between PT bins.
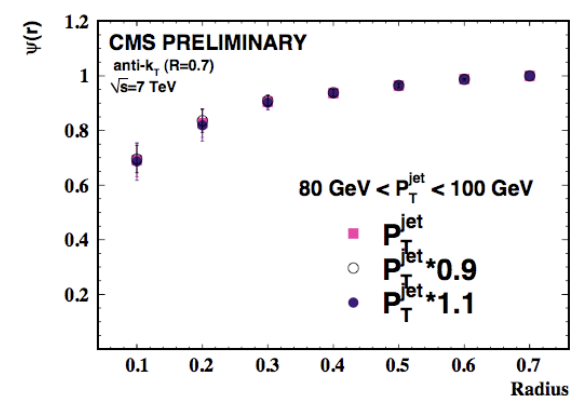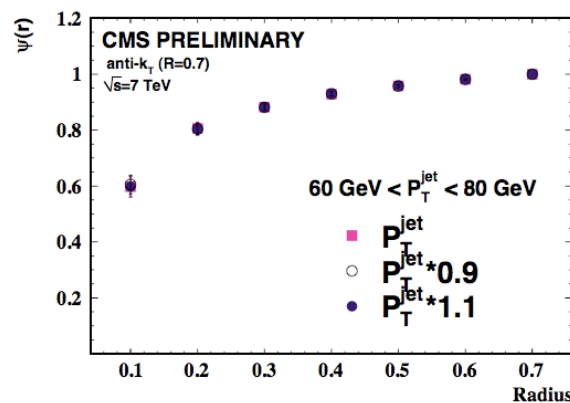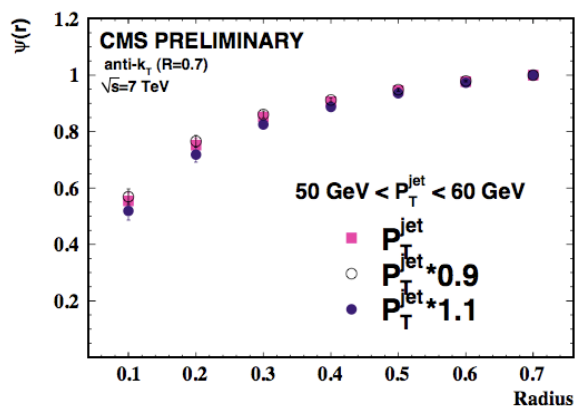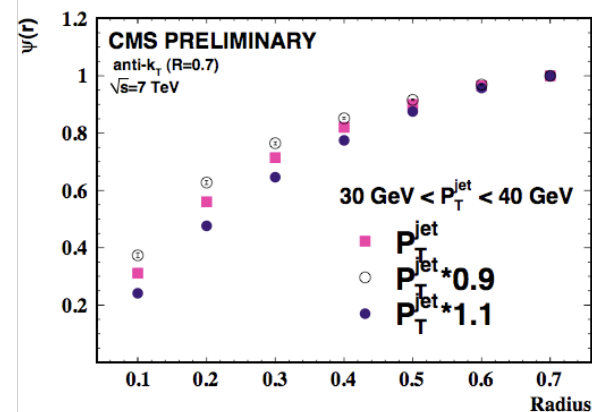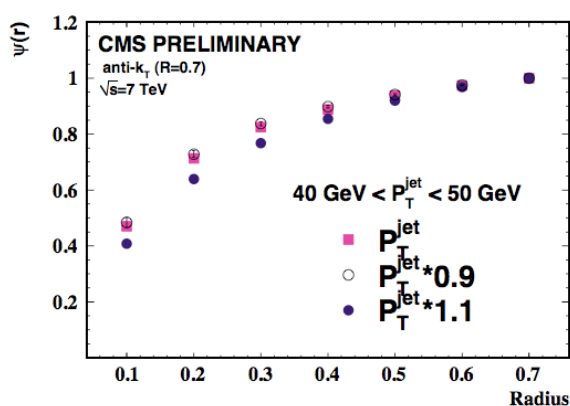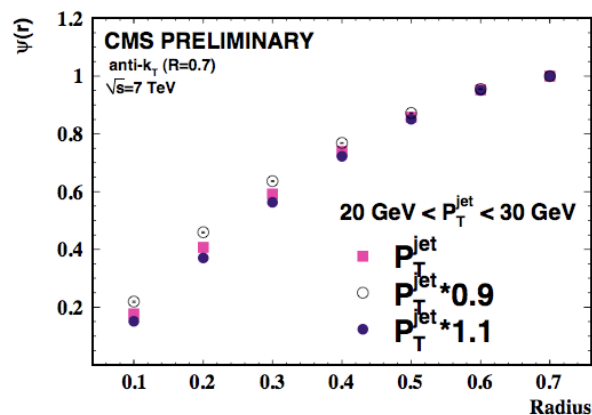
Integrated jet shapes
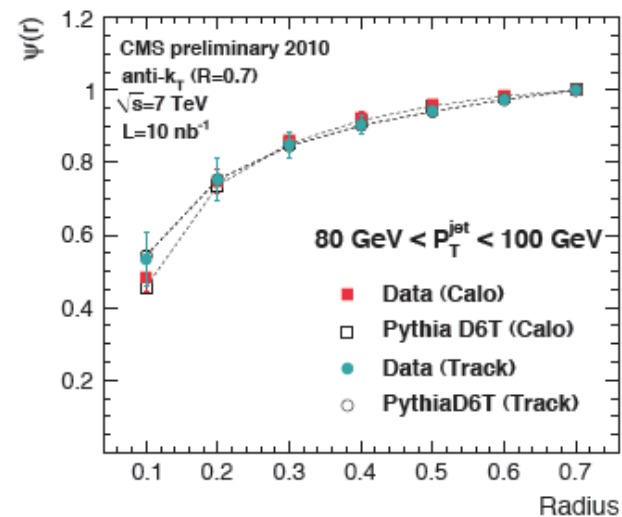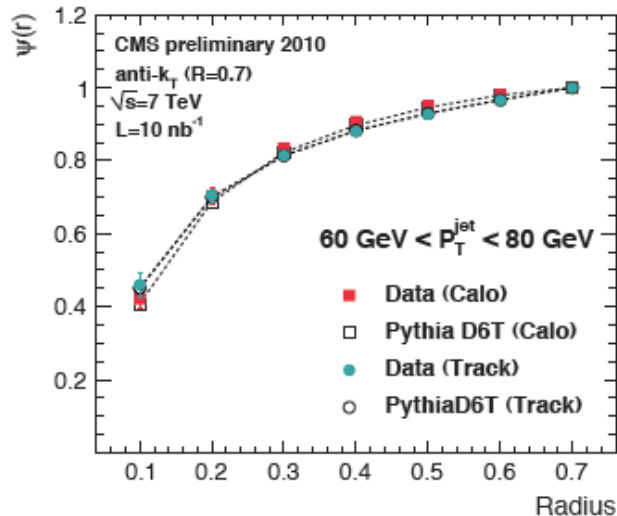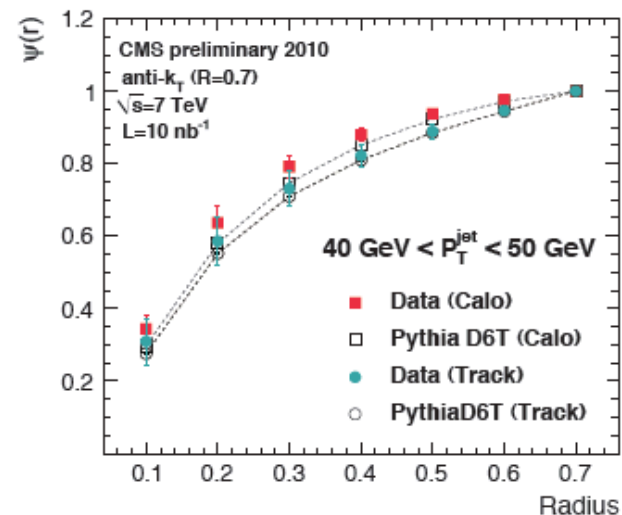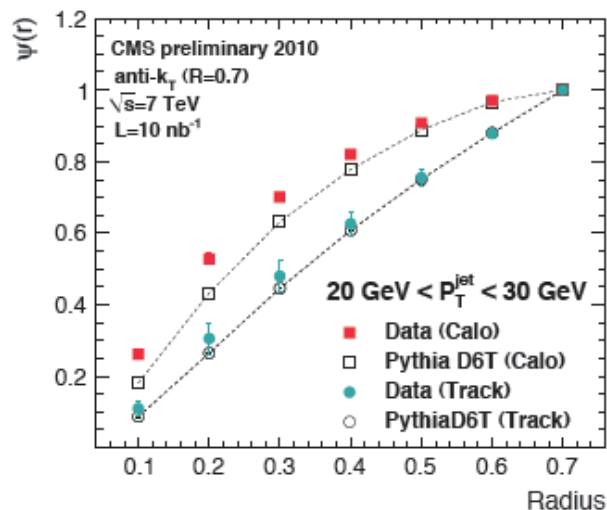
The jet shapes variables increase with pT indicating that jets are more collimated.

Sensitivities to PYTHIA tunes and Jet Fragmentation

Well tuned MC's are essential for precise measurements at LHC and for proper comparisons with theoretical predictions.
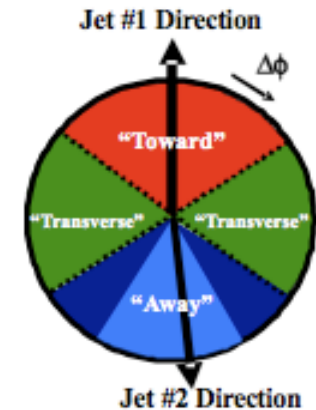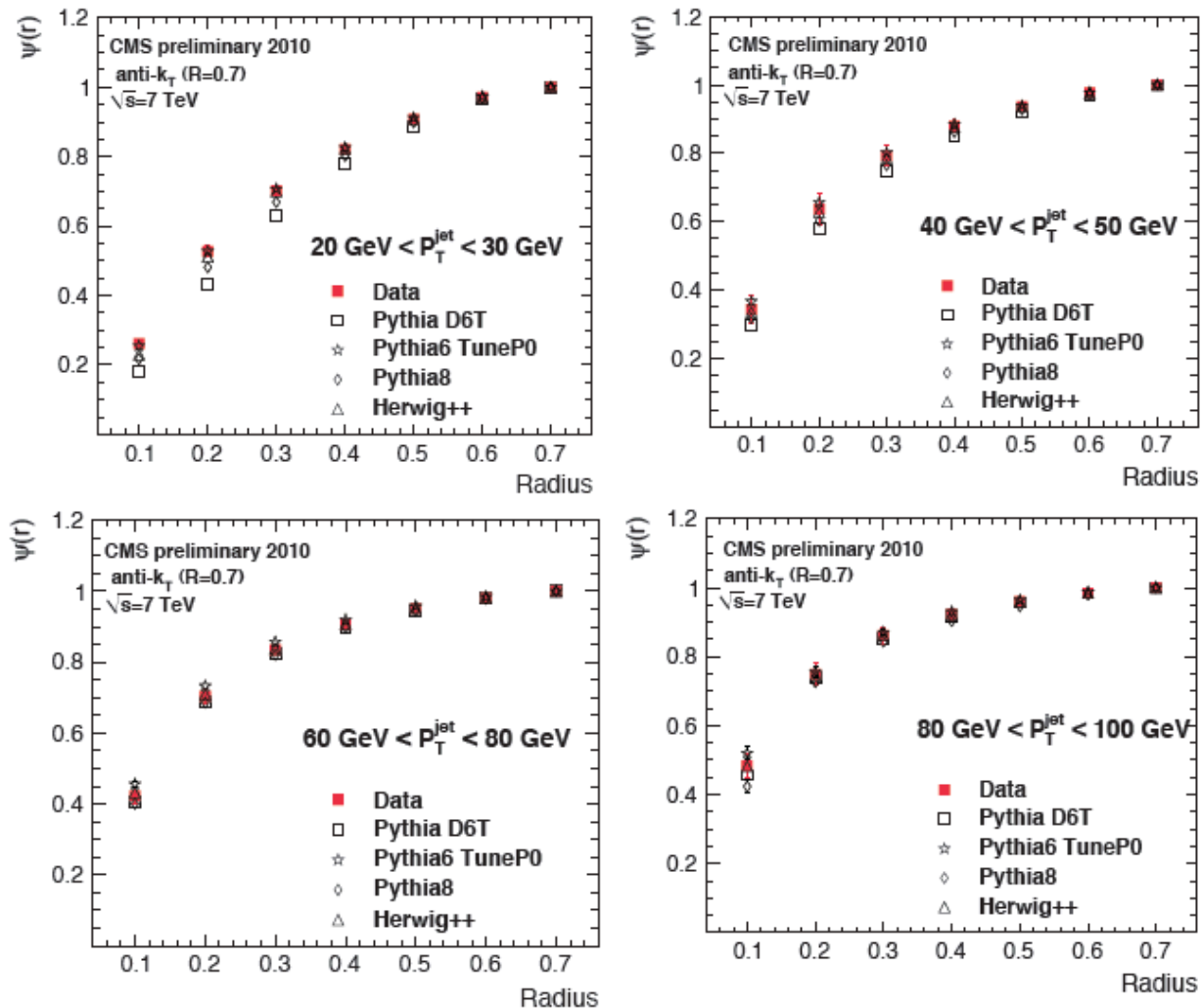
- The difference in UE contribution has visible effect especially at the very low Pt. Tune P0 has narrower jet shapes.

- HERWIG++ predicts narrower jet shapes than PYTHIA D6T and is in good agreement with data.

Quark and gluon jet shape differences

- Jet shapes are sensitive to quark-gluon jet mixture.
  - Can separate quark and gluon jets in a statistical way.
- Quark and Gluons jets radiate proportionally to their color factors
  - C_F: strength of gluon coupling to quarks.
  - C_A: strength of gluon coupling.

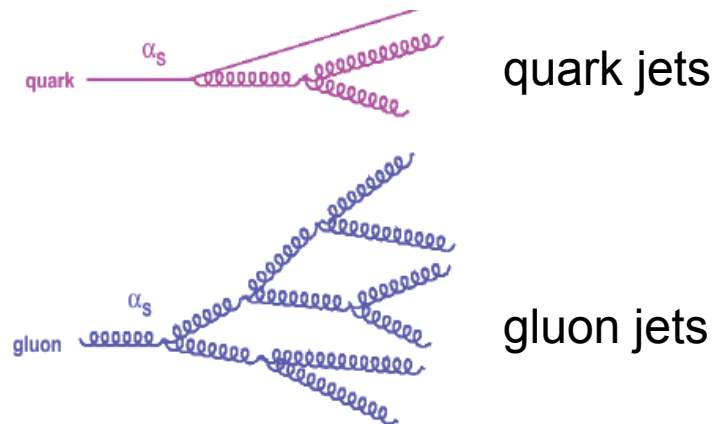$$\left| q \underset{}{\overset{}{\diagup}} \genfrac{}{}{0pt}{}{g}{q} \right|^2 \sim C_F = 4/3$$

quark jets

$$\left| g \underset{}{\overset{}{\diagup}} \genfrac{}{}{0pt}{}{g}{g} \right|^2 \sim C_A = 3$$

gluon jets

- In QCD, quark jets are expected to be narrower than gluon jets, but both get narrower with increasing jet p_T.
- Jets initiated by quarks and gluons are also expected to have different average multiplicities and p_T spectra of constituents.

Quark and gluon jets

CMS PRELIMINARY

$1 - \Psi (r=0.2)$

— gluon jets
-·-·- quark jets
········ particle jets
• corrected calojets

79% gluon

PYTHIA DWT
SISCone R=0.7
10pb^{-1}
38% gluon

$\sqrt{s}=14$ TeV
PYTHIA MC

Jet P_T [GeV]

Mostly Gluon Jets

Mostly quark jets

inclusive jets: Tevatron Run II
$|y|<0.4$
$qq \rightarrow$ jets
$gq \rightarrow$ jets
$gg \rightarrow$ jets

fractional contributions

X_T

p_T (GeV)
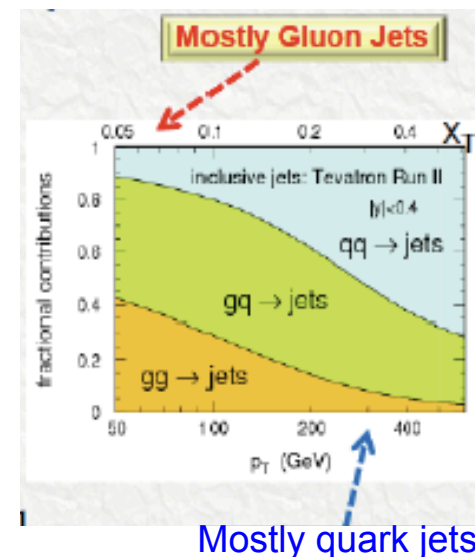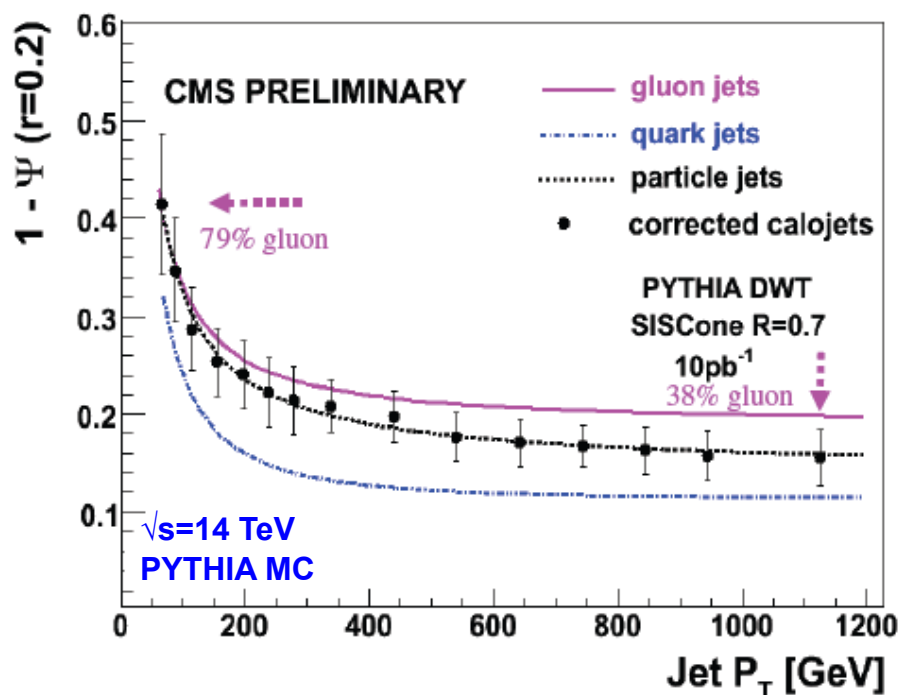
At small p_T, jet production is
Dominated by gg and gq
Scattering due to large
Gluon distributions at low x.

Observations:

❑   Quark jets are narrower than gluon jets.
❑   Fraction of gluon initiated jets decreases with increasing jet p_T.
❑   Mixture of quark and gluon initiated jets changes with jet p_T, contributing
    to the jet shape dependence on p_T.
❑ Jets become more collimated with increasing jet p_T.

Summary

- The charged particle multiplicity, the transverse jet shape δr^2 (as calculated from charged particles) and the integrated jets shapes have been measured with the first data recorded by CMS experiment. Statistics corresponds to integrated luminosity 10 nb^{-1} and 78 nb^{-1} at $\sqrt{s}$ =7 TeV.

- In general, the data follow trends expected from QCD as a function of the jet p_T.

- In the p_T jet range from 20 to 60 GeV we observe the difference between MCs (PYTHIA and HERWIG) and DATA for the transverse jet shape as measured from charged particles. For jet p_T > 80 GeV the statistics is not enough to make any conclusions.

- Jet shapes are sensitive to underlying event (at R~0 due to ψ(Rcone)=1), but not yet precise enough to differentiate between theoretical predictions.

- The data on the integrated jet shape is sensitive to the underlying event but not yet precise enough to differentiate between different theoretical prescriptions.

- From Monte Carlo studied the differences between quark and gluon jets.

Back up

Dijet Δφ in Data and MC

Δφ

dijet events are
back-to-back in
delta phi

Good agreement f
all jet types betwe
data and MC